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ABSTRACT

The concept to use a slab as active element, working in zig-zag geometry, and also as Fresnel rhomb, seems to be rather attractive. However, in this case different depolarization effects in active element are of crucial importance. We have carried out the estimations of depolarization effects arising both due to mechanical loading of an active element at its fastening and due to thermooptical distortions. To check up these rigid requirements to depolarization (0.1 % - 0.01 %) careful measurements of depolarization effects and their sources are being carried out. Mechanical loading gives one of the main contributions in depolarization at fastening of active element. Using model experiments with glass Fresnel rhomb under mechanical loading we have measured depolarization effects. It is proposed to use additional glass plate to compensate beam depolarization in zig-zag slab. The received results allow to expect successful use of the slab amplifier as a Fresnel rhomb providing rather high quality of optical material of active element.

Keyword: Fresnel rhomb, optical element, depolarization, multipass slab amplifier, depolarization compensator.

1. INTRODUCTION

Laser amplifier with large-aperture cross section is one of the major elements of laser systems for ICF. At present, disk amplifiers are mainly used for this purpose. At the same time there is a rich experience in development of large-aperture slab amplifiers of rectangular cross section [1,2,3] Such form of active element has definite advantages when used in zig-zag geometry. Success in development of anamorphic optics technology may remove the drawbacks connected with the high aspect ratio of the laser beam being amplified.

One of the possible ways to use the rectangular-cross-section amplifiers within laser system NIF is given in [3]. This amplifier was supposed to replace 16 rod amplifiers 5 cm in diameter. The scheme is presented in Fig. 1. Radiation from oscillator reaches 4-pass amplifier using rectangular cross-section active element in zig-zag geometry. Except the active element (Zig-Zag Amplifier) and the necessary turning mirrors (M1-M4) the scheme includes the polarizers P1,P2 needed to input the beam in the amplifier (P1) and to fulfill polarization isolation of the passes (P2). Two anamorphic telescopes (ART) are necessary to match the round aperture of the oscillator with the rectangular cross section of the amplifier and 16 disk canals of amplification. To be successfully used in NIF scheme , such amplifier must provide sufficiently high gain uniformity over the beam. The necessary beam uniformity over enough large area of the beam (0.5 of the total aperture area) was demonstrated in paper [3] for active element with dimentions of 45x400x430 mm ^{3}.

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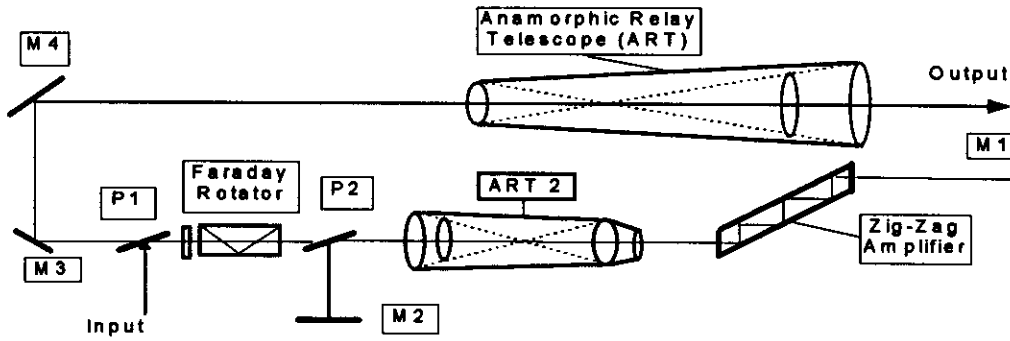


Fig. 1. This four-pass amplifier is intended to replace about sixteen rod amplifiers.

Another important components of any multi-pass amplification scheme are optical isolators necessary to prevent parasite generation in the resonator formed by the mirrors M1-M2. In [3] the Fresnel rhomb amplifier of rectangular cross section was proposed to be used as an element of optical isolator. At a given geometric size of active element, the beam undergoes 6 total internal reflections per a single pass through the amplifier (Fig. 2). Due to this fact the radiation polarized at the angle 45^0 to the axes of rectangular cross section changes polarization to orthogonal after two passes.

The quality of optical isolator necessary to prevent free lasing in the scheme considered is defined by the required gain. For the scheme with complete coincidence of forward and backward passes through the amplifier (Fig. 1), the mirrors M1 and M2 form a resonator with a threshold condition of free lasing

$$2 \cdot D \cdot R1 \cdot R2 \cdot K^2 = 1,$$

where D -the portion of radiation having polarization orthogonal to working polarization (depolarization degree) originating in each pass through the amplifier; R1, R2- the reflectivity of the mirrors M1 and M2 provided that (R1, R2 ≈ 1); K- gain factor per a pass. For the gain factor expected in this scheme K=10, the depolarization degree must not exceed $5 \cdot 10^{-3}$ Therefore to realize this proposal , low depolarization level should be provided of radiation propagating through the amplifier. The requirements towards depolarization may be reduced if to use the scheme with angular separation of forward and backward passes through the amplifier. However in this case , the design of anamorphic spatial filter becomes more complicated: for angular separation the double-slit diaphragm geometry is needed (Fig. 2). Besides, propagation of rays declined to the optical axis of anamorphic telescope causes additional optical distortions. The reason causing depolarization of the beam propagating through the active medium is internal mechanical stress. Let us consider the sources of stress.

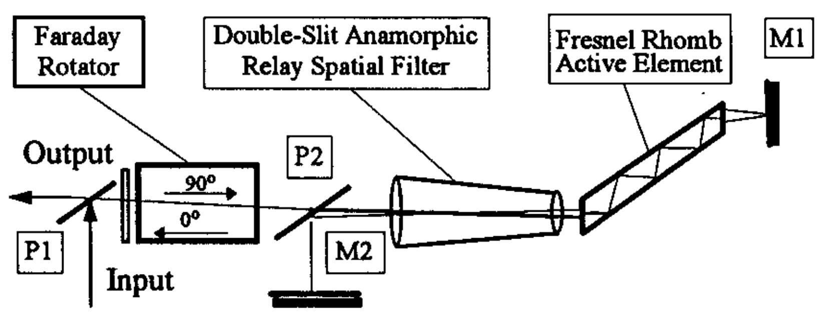


Fig. 2. Depolarization effects restrict the gain of amplifier due to free lasing.

2. THE SOURCES CAUSING MECHANICAL STRESS IN ACTIVE ELEMENT.

There are three sources of mechanical stresses in active element:

-thermoelastic stress;

-stress caused by outer forces (for example by fastening);

-residual stress after glass fritting

Variation of refraction index n leading to birefringence is connected with mechanical load by the following ratio:

$$\frac{\partial n}{\partial \sigma_{\parallel}} = C_1 \qquad \frac{\partial n}{\partial \sigma_{\perp}} = C_2$$

where $\sigma_{\perp}$ and $\sigma_{||}$ are the thermal stress tensor components which are orthogonal and parallel to the polarization vector, $\tilde{N}_1$, $\tilde{N}_2$ - photoelastic constants for light polarized perpendicular or parallel to the direction of internal strain. These changes in refraction index lead to wave-front distortions of the radiation passing through the amplifier.

2.1 Thermoelastic stress

Thermoelastic stress in active elements of rectangular cross section was studied in a number of works [4, 5, 6].

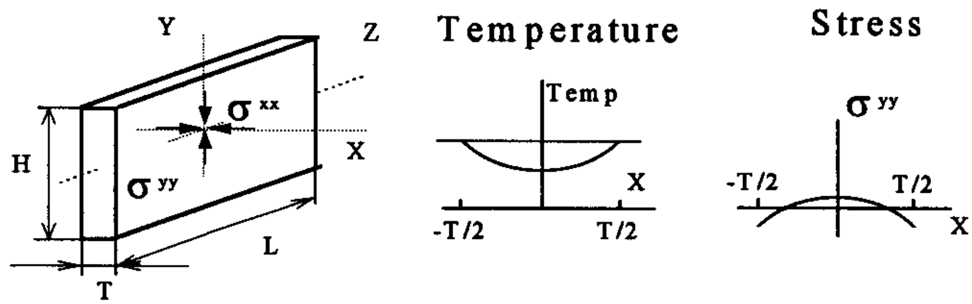
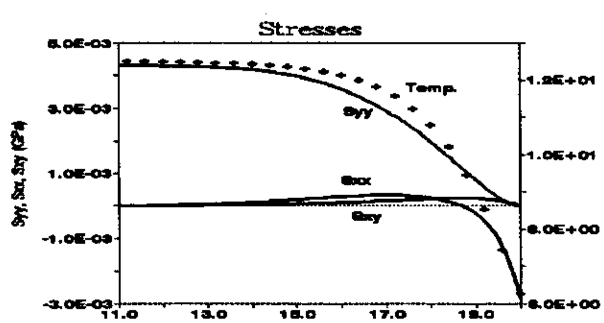


Fig. 3. The character of the distributions of the temperature and thermoelastic stress (σ_{yy}) inside slab.

According to the results of study in an infinite thin layer, stresses σ_{xx} are absent. Besides due to the equilibrium of internal stresses

$$\int_{-T/2}^{T/2} \sigma_{yy} dx = 0.$$

The character of the distributions of the temperature and thermoelastic stress (σ_{yy}) inside slab are presented in Fig. 3. In real devices, lamp panels provides uniform enough light flux, so that the temperature distribution resulting from light absorption in the active element of rectangular cross section may be considered to be one-dimensional with accuracy enough for practical goals (and symmetric with respect to the middle plane). Due to this the thermoelastic stress in the active element of rectangular cross section is properly described over almost the whole cross section by the approximation of thin layer and is not valid only close to the slab boundary (Fig. 4). Therefore in zig-zag propagation geometry the effective averaging of wave phase shift takes place.



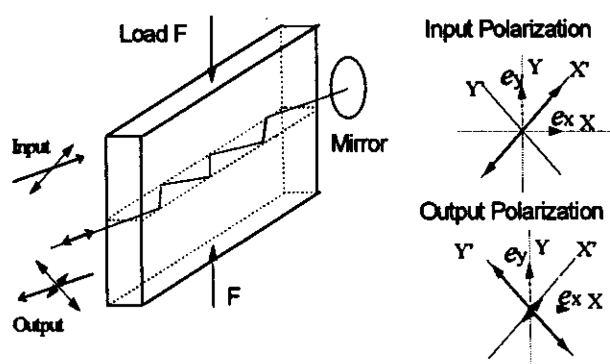


Fig. 4. Numerical simulation and experimental results show deviation from one-dimension model of stress distribution only near top/bottom boundary of active element.

Fig. 5. External loading results in depolarization.

Thus in first order approximation the thermoelastic stress arising in course of pumping doesn't result in beam depolarization. However, it should be mentioned that during element's cooling more complicated temperature fields arise capable to cause depolarization, the latter requiring additional experimental study.

2.2 Stress caused by external forces.

Unlike the internal stress that are mutually equalized and thus the effects caused by them may be averaged , the external loads may cause a remarkable depolarization (Fig. 5). For example, in the case of tough fastening of active element preventing its expansion, stresses σ arise causing beam depolarization $D = I_{dp}/I_o$ with wavelength λ while covering path L in the glass with $B= (C_1 - C_2)$

$$\sigma = E \cdot \alpha \cdot \delta T, \qquad D = \sin^2(\varphi), \qquad 0 < \varphi < (B \cdot \sigma \cdot L \cdot \frac{2 \cdot \pi}{\lambda})$$

where α - temperature expansion coefficient, E - Young's modulus, δT - average heating. For standard parameters of heating ($\delta T \sim 1.. 2°$, $\alpha \sim 10^{-5} / {}^0C$, Å~$5 \cdot 10^{10}$ Ðà, Â~$2 \cdot 10^{-12}$ Ðà$^{-1}$, L~0.5m) phase difference lies in the range $0 < \varphi < 4$ i.e. the beam depolarization turns out to be about 1. The given estimate shows the importance of fastening method. In the design developed by us the active element is fastened using springs providing constant force (~ 20 – 50 êg) not depending on mutual expansion of the active element and amplifier hardware. This force gives rise to a pressure (and respectively compression stress) < (0.1–0.25) kg/ffm^2 leading to additional depolarization not more than $(1\text{–}2.5) \cdot 10^{-2}$. Additional streess (0–0.1kg/ffm^2) is caused by the weight of active element. However, these relatively small values need to be taken into account while fastening.

2.3 Residual stress in glass.

It is well known that optical elements of large size have significant internal stress arising at glass cooling while manufacturing. To eliminate this stress, a special cooling regime is used allowing to get samples with low residual birefringence. However, in this case the depolarization of the beam propagating through the sample of large size (in our case the optical path per single pass is 58cm) may be of remarkable value. Depolarization measurements in the active element showed that its value is changed along the height of the active element and lies in the range < 1.5 %. However more detailed study of the residual birefringence should be carried out to have the use of a special object.

3. DEPOLARIZATION MEASUREMENTS IN FRESNEL RHOMB PRISM.

Measurements of depolarization caused by residual stress and external load were carried out at a standard Fresnel rhomb with aperture 5·5 cm^2. Experimental layout is given in Fig. 6. Radiation of He-Ne laser is split up into two beams with mutually orthogonal linear polarization with the help of a spar wedge. The beam having linear polarization oriented at the angle 45^0 towards the plane of incidence on the input plane is transmitted through Fresnel rhomb and reflected back using mirror. After double passes the beam falls again on the spar wedge. The polarization of the main beam after two passes through Fresnel rhomb becomes orthogonal to the initial one whereas the depolarized beam obtains the same polarization as the initial one. The optical signals reflected from the glass wedge are received by photo diodes and registered by oscilloscope. A mechanical modulator is used to distinguish signals from the noise of scattered radiation. There is the possibility to carry out the calibrated rhomb loading in two directions by forces F1, F2 and also to rotate the rhomb around the elevation axis to vary the incidence angle. The scheme allows to measure beam depolarization with the error of $\sim \pm 3 \cdot 10^{-4}$.

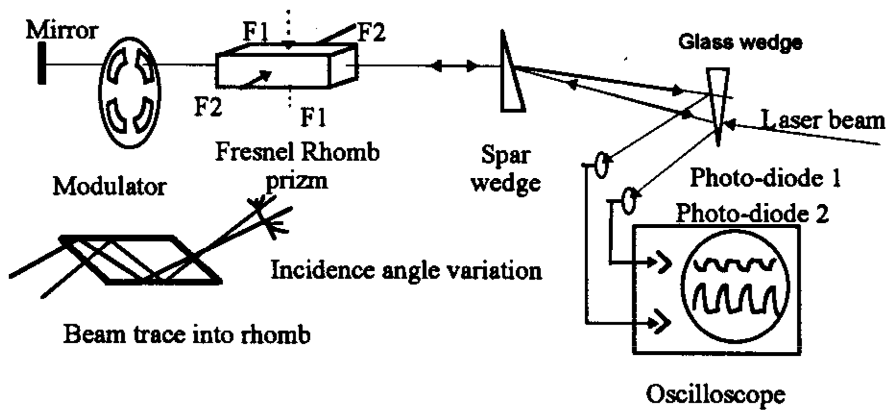


Fig. 6. The scheme allows to carry out depolarization measurements for different load F1-F2 and incidence angle

The polarization of the beam propagating forward and backward through the rhomb is defined by the phase difference of the components having electrical field vector lying in the plane of incidence or orthogonal to it. In addition, the phase difference connected with phase jump at total internal reflection is added to that obtained while propagating through the birefringence medium (through the stressed glass). Depending on the direction of the applied load, the phase difference caused by it, is either added or subtracted from the phase difference connected with wave reflection from the surface boundary. The effect of internal compression stress is equivalent to the load in the same direction whereas the stretch effect is equivalent to the compression in perpendicular direction. Fig. 7 shows dependence of phase difference (phase difference equal to π being subtracted) on the incidence angle at different loads; Fig. 8 shows the related depolarization. As it is seen from the figure the type of the dependence of beam depolarization on the incidence angle is defined by the value and sign of the applied loads. Such measurements give more complete picture and allow to determine not only the value but also the sign of the internal stress.

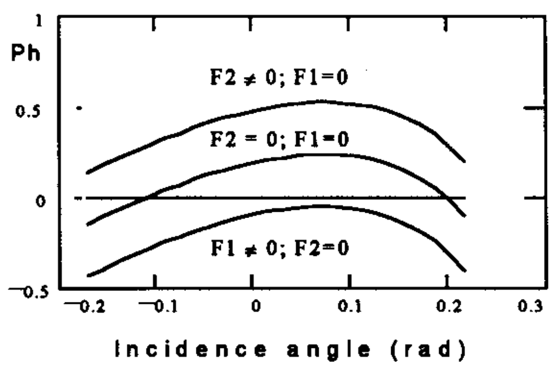


Fig. 7. Dependence of the phase shift (Ph) on incidence angle under different model loads.

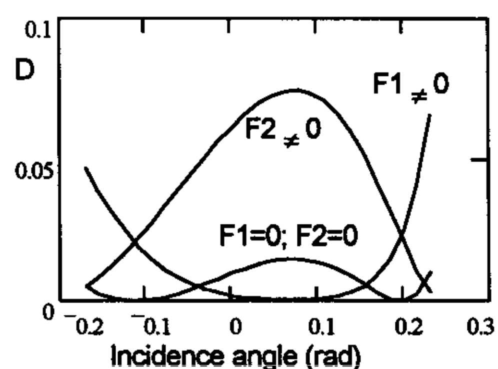


Fig. 8. Dependence of the depolarization (D) on incidence angle under different model loads.

Thus Fig. 9 presents the results of depolarization measurements after beam have twice passed the rhomb in different points of its aperture. The results illustrate that the depolarization value doesn't practically depend on the coordinate X of aperture in the plane of zig-zag passage. Note also that such kind of measurements doesn't allow to measure the sign of internal stress causing depolarization.

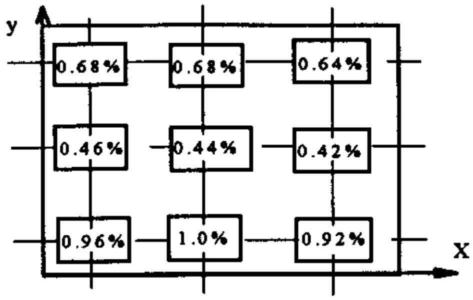


Fig. 9. Beam depolarization distribution over Fresnel rhomb prism aperture, outer load is absent

In Fig. 10 (a,b) the examples are given of depolarization D dependence on the incidence angle at different loads (F) and its comparison with the calculated curves. The calculated curves are obtained by selection of a model load using the criteria of the best agreement between the calculated and the measured angular dependencies. The qualitative change of curve's behavior for different loads is evident. Besides, the comparison of the calculated and the measured beams allows to define the value of internal stress integral along the beam. In Fig. 10 (c) the comparison is presented of the calculated and the measured values of depolarization D depending on the model load for a given incidence angle. In Fig. 10 (d) the comparison is given of real (measured) load and model load, testifying of the value (~ 45 êg) and the character (stretch) of internal stress averaged along the direction of propagation.

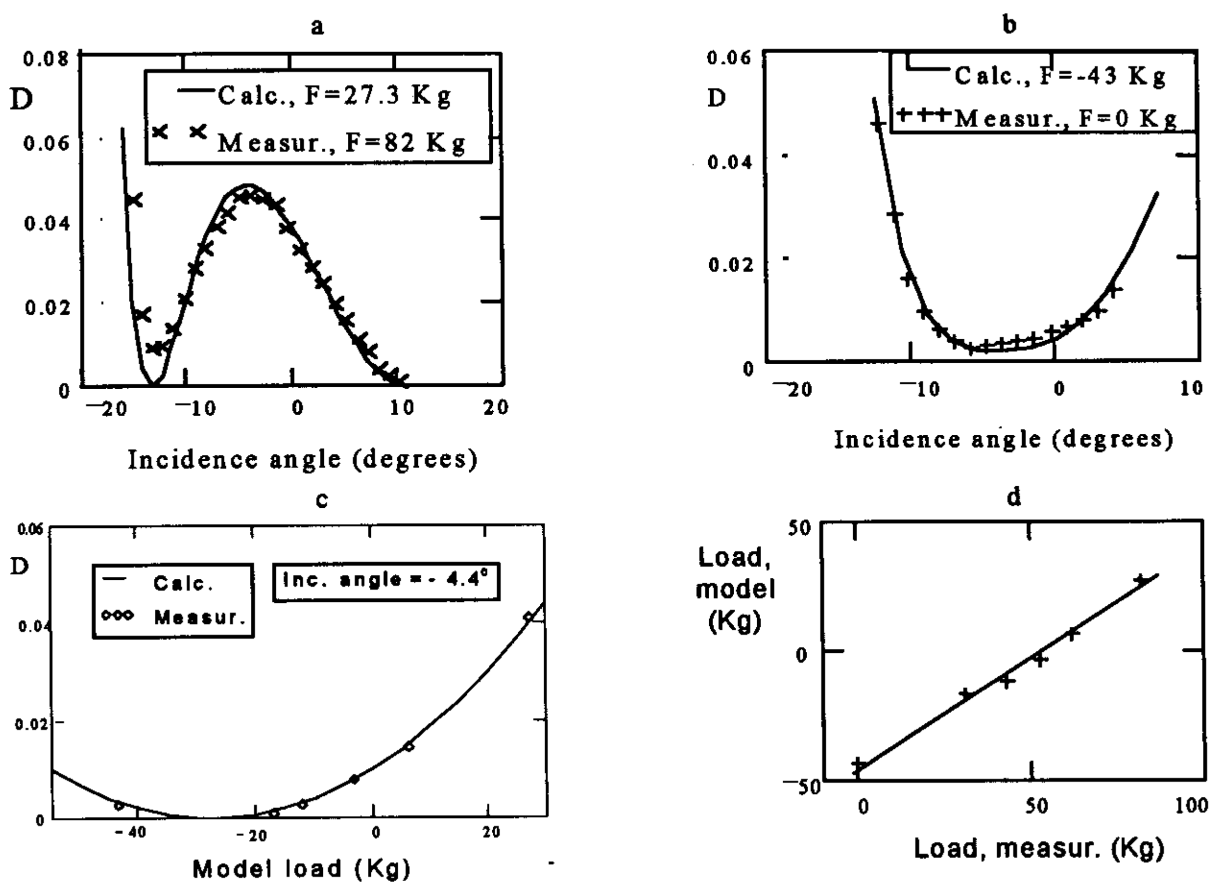
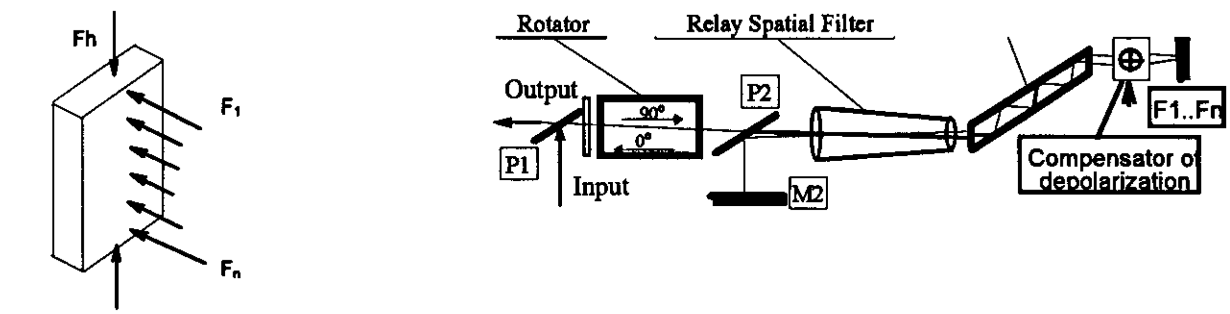


Fig. 10. Comparison of measured (markers) and calculated (solid lines) depolarization (D) curves show a sign of internal stresses (a, b).

4. COMPENSATOR OF DEPOLARIZATION

The measurement results allow to propose the design of a compensator for birefringence of Fresnel rhomb active element. Let us pay attention to two issues: 1) the depolarization doesn't depend on the coordinate X; 2) for the internal equalized loads there are areas both with compression and stretch stresses.



Compensator concept

Fig. 11. Compensator of depolarization which may be used into four-pass amplifier.

In Fig. 11 a draft of proposed compensator is given. The glass plate through which the beam passes is loaded in elevation (Fh) and plan (F_1-F_n) planes.

5. CONCLUSIONS

1. The experiments carried out with model loads allow to define the value and sign of internal stress averaged along the direction of beam propagation.
2. Model experiments show good agreement between the experimental and the calculated values of beam depolarization arising due to outer loads on Fresnel rhomb.
3. Using additional rectangular glass plate it is possible to make the device for compensation of the beam depolarization caused both by outer and internal stresses in active Fresnel rhomb.

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